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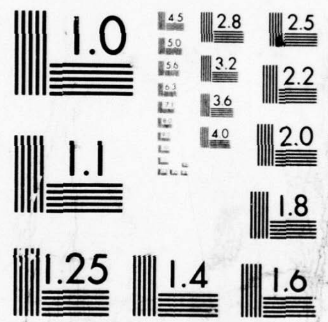

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MILITARY ENGINE OILS AS HYDRAULIC/POWER TRANSMISSION FLUIDS IN ARMY COMMERCIAL CONSTRUCTION EQUIPMENT

INTERIM REPORT
AFLRL No. 113

by

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CCE	Fluid Power	Construction Equip	Chatter
Brakes			Vehicles

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In 1971, the Army adopted a policy of procuring commercial-type construction and other off-highway equipment, referred to as CCE. With this equipment comes the equipment builder's warranty which requires use of hydraulic power transmission fluid (HPTF) which meets his specification. The fact that many different equipment suppliers will ultimtely furnish their products to the military under this arrangement leads to the possible proliferation of proprietary fluids in the government supply system. To counteract this

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20. ABSTRACT (cont'd)

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possibility, and hopefully eliminate such proprietary fluids, MERADCOM/ AFLRL undertook an extensive experimental program aimed at determining the feasibility of using existing government-stocked lubricants in CCE HPTF systems. Since early procurement involved usage of a John Deere Company proprietary fluid, the initial thrust of the lubricants test work was aimed at developing a suitable compromise/minimal tradeoff replacement fluid for the John Deere materials specification JDM-J20A product.

Fourteen test oils were compared against the John Deere proprietary reference oil in laboratory bench, wet-brake, and full-scale wear tests. Lubricants included nine qualified Military Specification engine oils, three commercial automatic transmission fluids (ATF), and two commercial type tractor hydraulic fluids. Results show a MIL-L-2104C OE/HDO-10, a MIL-L-46152 grade 10W-30, and a commercial universal-type tractor hydraulic fluid produced overall good performance--equal to or better than the proprietary reference fluid--in all areas tested. One MIL-L-46167 synthetic arctic engine oil (OEA) produced generally acceptable overall results, and the other OE/HDO-10 grade products produced generally acceptable results in the most critical performance areas.

The military specification automotive engine lubricants, namely MIL-L-2104C OE/HDO-10, MIL-L-46167 OEA, and MIL-L-46152 grade 10W-30 proved to be equal or better in regards to gear wear than the John Deere proprietary fluid. Although some of the military specification fluids produced more wet-brake chatter than the John Deere fluid, one MIL-L-2104C OE/HDO-10 product, one MIL-L-46152 10W-30 product and a 50/50 blend of these two had equal or superior brake chatter performance. Two of the lubricants, namely MIL-L-2104C OE/HDO-10 and MIL-L-46167 OEA, were also evaluated in the Caterpillar TO-2 and Allison C-3 friction tests and both exceeded the John Deere specification product and the manufacturers' requirements. In-vehicle brake chatter, overall hydraulic system performance, and long-term lubricant effects are being evaluated at two Army facilities in a continuing effort. Recommendations for extended laboratory testing and eventual withdrawal of the proprietary fluid are made.

FOREWORD

The work reported herein was conducted at the U.S. Army Fuels and Lubricants Research Laboratory (AFLRL), Southwest Research Institute, San Antonio, Texas, under Contracts DAAG53-76-C-0003 and DAAK70-78-C-0001. The work was funded by the U.S. Army Mobility Equipment Research and Development Command (MERADCOM), Ft. Belvoir, VA. Contracting Officer's representative was Mr. F.W. Schaekel, Fuels and Lubricants Division, Energy and Water Resources Laboratory (DRDME-GL).

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The authors acknowledge the assistance provided by the staff of their respective organizations; the engineering personnel at John Deere Waterloo and Dubuque Works; the personnel at Ft. Belvoir Engineering Proving Ground, Ft. Sam Houston 63rd Engineering Detachment, and Ft. Hood 62nd Engineering Construction Battalion; and special recognition to Mr. A.D. Brownlow at SwRI who assisted in the conduct of the full-scale laboratory evaluations.

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I. INTRODUCTION/BACKGROUND

The basic methods within the Army for procurement of construction equipment in the past were for the Army to develop its own or to modify commercially available items to meet mission requirements. The former method required the full research, development, testing and evaluation (RDTE) acquisition cycle to produce a finished item which often resulted in the belated consideration of timely developments occurring in new technologies. Although the latter method avoided some of the R&D costs, it still required considerable investment to develop military modifications followed by the need to conduct extensive formal Army testing.

In many aspects the Army's military construction mission resembles the tasks of civilian construction enterprises. These construction companies practice continuous competition through improvements and modernization of equipment through research and development. Recognizing the same need for modernization and being simultaneously confronted with decreasing R&D budgets, the Army adopted a policy of procuring construction-type equipment (CCE) from commercial sources.(1)* In other words, the Army purchased standard "off-the-shelf" equipment to accomplish its construction tasks.

Although obvious advantages exist for this policy, certain problems require resolution to make the CCE program successful. As a case in point, construction equipment is normally purchased under a CCE specification that requires use of military lubricants.(2) However, many equipment items have supplier-imposed lubrication requirements which can only be satisfied by using the manufacturer's proprietary fluids. Using the manufacturer's fluids would obviously lead to a proliferation of proprietary hydraulic fluid specifications creating a logistic burden to the supply system. However, use of fluids not authorized by the equipment manufacturers would lead to the loss of equipment warranty, and many of the manufacturers are reluctant to permit use of nonproprietary fluid in their equipment.

For military construction equipment without wet brake systems, automotive engine oils meeting MIL-L-2104C, Lubricating Oil, Internal Combustion Engine,

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*Numbers in parentheses refer to references at the end of this report.

Tactical Service[3], and MIL-L-46167, Lubricating Oil, Internal Combustion Engine, Arctic[4] have been and are currently being used for practically all Army hydraulic and power transmission fluid (HPTF) applications. With the introduction of the CCE programs, John Deere and Company was awarded a contract to furnish a CCE item which introduced the first wet-brake equipped commercial vehicle into the Army in 1975. Since subsequent contract procurements could be awarded to other companies like Massey-Ferguson, Oliver, International-Harvester, J.I. Case, Ford, etc., there was great concern within the Army as to potential supply problems since each of these companies required that its proprietary hydraulic fluids be used. These companies indicated that MIL-L-2104C automotive engine oils would not perform satisfactorily in their respective equipment systems.[5] Examples of the variations in HPTF system requirements are given in Tables 1 and 2.

The Army's concern about proliferating HPTF requirements had already been brought to the attention of the American Society of Testing and Materials and the Society of Automotive Engineers in 1974 with a request to consider development of a multipurpose hydraulic fluid.[6] However, no agreement was obtained as each equipment manufacturer preferred its own proprietary fluid, and again stated that MIL-L-2104C engine oils would produce problems if used. Since industry was unable to provide assistance at this time, MERADCOM elected to consider development of an universal hydraulic fluid for construction equipment which would reduce the multiple fluid requirements and, at the same time, comply with MIL-STD-838B (Lubrication of Military Equipment) which states that all lubricants used in military equipment shall be standard lubricants.[2]

For this purpose, MERADCOM initiated a test program in 1975 to establish the performance levels of a number of existing military specification lubricants and several commercial and Government stocked hydraulic and power transmission fluids in relation to the John Deere JDM-J20A factory and service fill specification.[7] In accomplishing this test program, MERADCOM would ascertain the level of performance debit in using MIL-L-2104C oils reported to occur by equipment manufacturers.

TABLE 1. WHEELED-TRACTOR MANUFACTURERS' REQUIREMENTS FOR HYDRAULIC AND POWER TRANSMISSION FLUIDS

Manufacturer Specification	Allis-Chalmers PF-821	Ford M2C134-A	International Harvester B-6	J. I. Case TCH-145	John Deere JDM-J20A	Massey-Ferguson M-1136	Minneapolis-Moline 35301	Oliver S-3727-B
K. Viscosity, cSt								
at 100°F (37.8°C)	X	NR	NR	NR	NR	NR	X	X
at 210°F (98.9°C)	X	X	X	X	X	X	X	X
Stability	NR	X	X	X	X	X	X	NR
Index, cP	NR	NR	X	X	NR	X	X	NR
0°F (-17.8°C)	X	X	X	X	X	X	X	NR
-20°F (34.4°C)	NR	NR	X	NR	NR	NR	NR	NR
Flash Point, °F (°C)	X	X	X	X	X	NR	X	X
Fire Point, °F (°C)	NR	X	NR	X	NR	NR	X	NR
Pour Point, °F (°C)	X	X	X	X	X	X	X	X
Rust Protection	X	X	X	X	X	X	X	NR
Corrosion	X	X	X	X	X	X	X	X
Antifoam	X	X	X	X	X	X	X	X
Rubber Compatibility	X	X	X	X	X	X	X	NR
Compatibility w/Other Oils	X	X	X	X	X	NR	X	NR
Oxidation & Thermal Stability	X	X	X	X	X	X	X	NR
Friction, Clutch and/or Brake	NR	X	X	X	X	NR	X	X
Transmission Durability	X	X	X	NR	X	X	X	NR
Wear Protection	X	X	NR	X	X	X	X	NR
Toxicity	NR	X	NR	X	NR	X	X	NR
Miscellaneous								
API Gravity	NR	NR	NR	NR	NR	NR	X	NR
Aniline Point	NR	NR	X	NR	NR	NR	X	NR
Color	NR	NR	X	NR	NR	NR	NR	X
Hydraulic Performance	NR	NR	X	X	NR	NR	NR	NR
Metals	X	X	NR	NR	NR	NR	NR	NR
Neutralization Number	NR	NR	NR	NR	NR	NR	X	X
Odor	NR	X	NR	NR	NR	NR	X	NR
Precipitation Number	NR	NR	NR	NR	NR	NR	X	NR
Saponification	NR	NR	NR	NR	NR	NR	NR	X
Water Sensitivity	NR	NR	X	NR	X	NR	NR	NR

X—Determine.
NR—Not Required.

II. TEST DETAILS

A. Test Lubricants

For this test program, 15 test lubricants were evaluated. Each of the lubricants was designated with a code letter for laboratory use. The code letter for each lubricant, along with its specification, type, and description, is shown in Table 3. Included in the program is the John Deere JDM-J20A Specification reference (JD Ref) oil, which is used as factory and service fill by

TABLE 2. MANUFACTURERS' REQUIREMENTS FOR HYDRAULIC AND POWER TRANSMISSION FLUIDS IN CRAWLER TRACTORS

Manufacturer Specification	Allison C-3	Allis-Chalmers & Fiat Allis GM-6137-M	Caterpillar CD/TO-2	International Harvester B-6	J. I. Case TCH-145	John Deere JDM-J20A
K. Viscosity, cSt						
at 100°F (37.8°C)	X	NR	X	NR	NR	NR
at 210°F (98.9°C)	X	X	X	X	X	X
Stability	NR	NR	X	X	X	X
Index	NR	NR	X	X	X	NR
0°F (-17.8°C), cP	X	X	X	X	X	X
-20°F (34.4°C), cP	X	X	NR	X	NR	NR
Flash Point, °F (°C)	NR	X	X	X	X	X
Fire Point, °F (°C)	NR	X	NR	NR	X	NR
Pour Point, °F (°C)	X	NR	X	X	X	X
Rust Protection	X	X	NR	X	X	X
Corrosion	NR	X	X	X	X	X
Antifoam	X	X	X	X	X	X
Rubber Compatibility	X	X	NR	X	X	X
Compatibility w/ Other Fuels	NR	X	X	X	X	X
Oxidation and/or Thermal Stability	X	X	NR	X	X	X
Friction, Brake and/or Clutch	X	X	X	X	X	X
Transmission Durability	NR	X	NR	X	NR	X
Wear Protection	X	X	NR	NR	X	X
Toxicity	NR	X	NR	NR	X	NR
Channel Point	NR	NR	NR	NR	NR	NR
API Gravity	NR	NR	X	NR	NR	NR
Aniline Point	NR	NR	NR	X	NR	NR
Color	NR	X	NR	X	NR	NR
Hydraulic Performance	NR	X	NR	X	X	NR
Sulfated Residue	NR	NR	X	NR	NR	NR
Insolubles	NR	NR	NR	NR	NR	NR
Water Sensitivity	NR	NR	NR	X	NR	X
Metals	NR	X	X	NR	NR	NR
Stable Pour Point	NR	NR	X	NR	NR	NR
Carbon Residue	NR	NR	X	NR	NR	NR
Phosphorus	NR	X	X	NR	NR	NR
Chlorine	NR	NR	X	NR	NR	NR
Sulfur	NR	X	X	NR	NR	NR
Nitrogen	NR	NR	X	NR	NR	NR
Low-Temperature Deposits	NR	NR	X	NR	NR	NR
Bearing Corrosion	NR	NR	X	NR	NR	NR
Ring-Sticking, Wear, Deposits						
Medium-Speed	NR	NR	X	NR	NR	NR
High-Speed	NR	NR	X	NR	NR	NR
Fluids Used in Other Compartments						
GM 6137-M	NR	X	NR	NR	NR	NR
MIL-L-2104C	NR	X	X	X	NR	X
MIL-L-2105C	NR	NR	NR	X	X	X

X—Determine.
NR—Not Required.

TABLE 3. TEST LUBRICANTS FOR JOHN DEERE CCE HPTF COMPATIBILITY STUDIES

LUBRICANT CODE	SPECIFICATION	LUBE TYPE	DESCRIPTION
A	JDM-J20A	HPTF	JD Ref Oil
B	MIL-L-2104C (1)	OE/HDO-10	Army Fielded Oil
C	MIL-L-46152 (1)	10W-30	Army Fielded Oil
D	MIL-L-46167 (1)	OEA*	Army OEA & Arctic HPTF
E	MIL-L-46167 (2)	OEA*	Army OEA & Arctic HPTF
F	Ford M2C33F	ATF	Type F
G	GM 6137-M	ATF	DEXRON-II (C)
H	GM	ATF	DEXRON (B)
I	MIL-L-46152 (2)	10W-30	Army QP
J	Various Commercial	HPTF	"Universal HPTF"
K	IH B-6	HPTF	IH FF/Service Oil
L	MIL-L-2104C (1A)	OE/HDO-10	Army Fielded Ref Oil
M	MIL-L-46152 (3)	10W-30	Army Fielded Oil
N	MIL-L-2104C (2)	OE/HDO-10	Army Fielded Oil
O	MIL-L-2104C (3)	OE/HDO-10	Army Fielded Oil

* Nominal 5W-20 Grade, not a requirement.

the equipment manufacturer. In this work, the JD Ref oil provides the basis for comparison with all other test oils. In this report, this fluid is referred to simply as the reference oil, or as oil "A" from Table 3. Products from three military specifications[3,4,8] are shown in the table, along with three commercial automatic transmission fluids (ATF)[9-11] and two commercial hydraulic power transmission fluids (HPTF). The numbers in parentheses in Table 3 refer to different suppliers of products within one of the three military specifications. All MIL-L-2104C oils are referred to as OE/HDO-10, all MIL-L-46152 oils are referred to as 10W-30, and all MIL-L-46167 oils are referred to as OEA. All the military lubricants are qualified products, and eight of the nine were obtained from the military supply system. The Ford and General Motors ATF's are normally available in the military supply due to their extensive use in GSA and military administrative vehicle automatic transmission/power steering systems. The International Harvester IH B-6 fluid and the commercial-universal HPTF are not available in the military supply system, but were selected for test because of significant interest in these two types of products.

B. Test Procedures

The test procedures used in this program included the JDM-J20A physical/chemical property, bench, and full-scale friction and wear tests. These tests are shown in Table 4 where it is noted that either standard/modified ASTM tests or proprietary tests developed by the equipment supplier were used. In addition, elemental analyses were determined by x-ray fluorescence or atomic absorption.

Two different wet-brake test procedures were used--the equipment manufacturer's and an Army Laboratory (AFLRL) modified version. Each procedure is described in Appendix A.

C. Field Evaluations

In-vehicle evaluations were conducted at three Army bases using a total of five vehicles. These tests included determination of vehicle drivability, hydraulic system operability, brake capacity/stall, and brake chatter/noise. These were limited tests in that larger numbers of vehicles and test lubricants would have been more desirable. The vehicles were evaluated with the lubricant that was in the vehicle when obtained. Also, controlled evaluations using selected test lubricants were performed. In addition, extended use/durability tests are being conducted in a limited number of vehicles to determine long-term fluid effects. These field evaluation test procedures are described in detail in Appendix B.

III. DISCUSSION OF RESULTS

The nine Army-qualified engine lubricants, three government procured automatic transmission fluids, and three commercial hydraulic fluids were evaluated using the John Deere JDM-J20A chemical/physical specification and the wet-brake chatter tests. Six of these lubricants--three MIL-L-2104C OE/HDO-10, a MIL-L-46167 5W/20 arctic engine oil, and two MIL-L-46152 10W/30 oils--were selected for testing in the JDM-J20A full-scale performance tests. These six possible compromise lubricants, along with the JD Ref fluid, were also evaluated by in-vehicle field tests in Army John Deere 410 front loader/backhoe tractors. Also, three of the lubricants were evaluated in the Caterpillar

TABLE 4. JOHN DEERE JDM-J20A SPECIFICATION

	Test Method	
Physical Requirements	ASTM	Other
K. Viscosity, cSt (m^2/s)		
New Oil @ 100°F (37.8°C)	D 445	
New Oil @ 210°F (98.9°C)	D 445	
Oil at end of 30 min, sonic shear	D 2603 mod	
Brookfield Viscosity, cP (mPa/s)		
New Oil @ 0°F (-17.8°C)	D 2983	
New Oil @ -30°F (-34.4°C)	D 2983	
Flash Point, °F (°C)	D 92	
Pour Point, °F (°C)	D 97	
Bench Test Requirements		
Oxidation, 100 hr @ 300°F (148.9°C)		Prop
Evaporation Loss, %		
Vis Increase @ 210°F (98.9°C)		
Sludge Formation		
Additive Separation		
Rust Protection, in humidity cabinet, 100 hr	D 1748 mod	
Copper Strip Corrosion, 3 hr @ 300°F (148.9°C)	D 130 mod	
Antifoam	D 892 mod	
Sequence I, ml foam		
Sequence II, ml foam		
Foam Break Time, s		
Sequence III, ml foam		
Water Sensitivity, photograph		Prop
Sediment, vol%		
Additive Loss, % mass		
Extreme Pressure	D 2782 mod	
Timken OK load, lbf (N)		
Timken Abrasion, 6 hr @ 10 lbf (45 N)		
Mass Loss, mg		
Contact Pressure, psi (Pa)		
Compatibility With Rubber, 70 hr @ 212°F (100°C)	D 471 mod	
Vol Change, %		
Hardness, points durometer		
Precipitation		
Compatibility With Other Oils		Prop
Additive Separation		
Antifoam	Same as above	
Oxidation	Same as above	
Performance Requirements		
Transmission Final Drive Gear Wear		Prop
Left Hand, in. (mm)		
Right Hand, in. (mm)		
PTO Clutch Stall & Breakaway		Prop
Coefficient of Friction		
Wear, Front, in. (mm)		
Back, in. (mm)		
Wet-Brake Test		Prop
Torque Capacity, units		
Chatter Variation, units		

Prop = Proprietary test developed by equipment manufacturer

TO-2 and Allison C-3 friction tests to confirm expected acceptable performance in these highly used Army transmission/friction systems. From these combined data, a MIL-L-2104C OE/HDO-10 lubricant was selected for limited extended-use field testing. These tests are now being monitored for hydraulic performance and lubricant conditions. This test and evaluation sequence is illustrated in Figure 1.

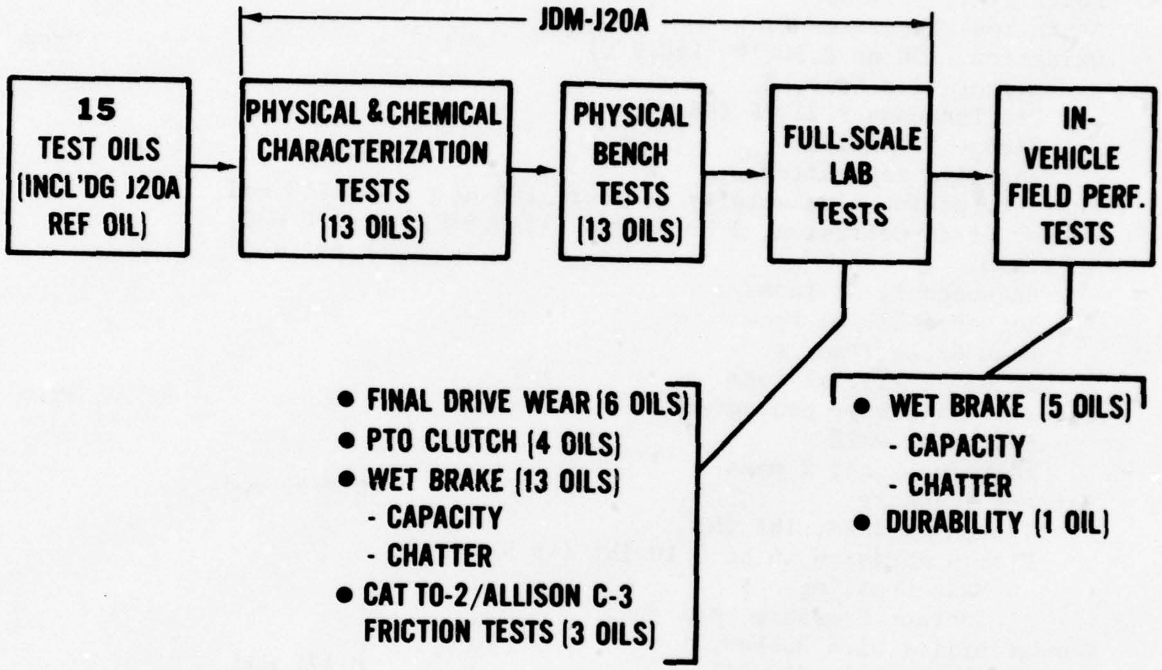


FIGURE 1. TEST AND EVALUATION SEQUENCE FOR COMPROMISE CCE HPTF DEVELOPMENT

A. Chemical/Physical Property Tests

Lubricants A through M, listed in Table 3, were subjected to all the chemical/physical tests of the John Deere JDM-J20A specification (see Table 4), and results are summarized in Table 5. In MIL-L-2104C OE/HDO-10 lubricants N and O, only the viscosity, flash point, and pour point tests (see Table 5) were performed. In addition, the additive elemental composition was determined for all fifteen lubricants, and these results are included in Table 5.

Viscosity--The kinematic viscosity was tested using the ASTM D 445 specification, and the sonic shear used ASTM D 2603 with a modification for standardizing the operating severity. Only five of the fifteen lubricants, A (JD Ref), C (10W-30), I (10W-30), J (HPTF), and M (10W-30), met the minimum kinematic viscosity of 9.1 cSt at 210°F (98.9°C). These same five lubricants also met the minimum viscosity of 7.1 cSt at 210°F (98.9°C) after 30 minutes of sonic shear. It should be noted that of the ten lubricants that failed to meet the initial 9.1-cSt viscosity specification, four--B (OE/HDO-10), D (OEA), L (OE/HDO-10), and K (HPTF)--did not have any significant viscosity loss due to sonic shearing. Of the thirteen Brookfield viscosities run at 0°F (-17.8°C), all passed. However, at -30°F (-34.4°C), the viscosities for two lubricants--B (OE/HDO-10) and K (HPTF)--did not meet the specification of 70,000 cP maximum.

Flash Point--Of the lubricants, 14 met the minimum requirement of 390°F (198.9°C), with only ATF lubricant F the failing to meet the specification.

Pour Point--Of the 15 lubricants, 7 did not meet the -35°F (-37.2°C) requirement; these included B, H, J, K, L, N, and O.

Elemental Composition--Table 5 lists the elemental composition of the additive systems used in the test lubricants. These data were assembled in an attempt to correlate chemical element composition with the JDM-J20A bench tests and the wet-brake chatter performance. From these analyses, it was not possible to relate additive elements per se or concentration level to passing or failing performance in any of the JDM-J20A tests.

B. Bench Tests

For this program, ten bench tests were conducted in accordance with the JDM-J20A specification for 12 of the test oils. Only the oxidation and extreme pressure wear tests were conducted on two of the lubricants, codes N and O. All bench test results are presented in Tables 6 and 7.

Antifoam--This test uses the ASTM D 892 method with the modification of reporting the time for foam collapse. Of 13 lubricants tested in the foam test, only two--D (OEA) and E (OEA)--failed to pass the test. Lubricant K (HPTF)

TABLE 5. RESULTS FOR JDM-J20A SPECIFICATION PHYSICAL PROPERTY TESTS AND CHEMICAL COMPOSITION

Lubrication Code		A	B	C	D	E	F
Description		JD Ref	OE/HDO-10	10W/30	OEA	OEA	ATF
Physical Properties	Limit						
K. Viscosity, cSt							
New Oil at 210°F (98.9°C)	9.1 min	9.76	6.64	10.48	6.14	6.53	8.11
New Oil at 100°F (37.8°C)	Report	67.73	46.10	58.49	29.32	35.11	43.12
Loss of Viscosity @ 210°F (98.9°C) After 30 min Sonic Shear	7.1 min	8.2	6.7	8.7	6.2	5.7	6.4
Reference Oil "A"			Viscosity	@ 210°F	(98.9°C)	Initial	= 11.2 cSt
Brookfield Viscosity, cP/mPa·s							
@ 0°F (-17.8°C)	4500 max	3750	2490	3160	880	950	1420
@ -30°F (-34.4°C)	70,000 max	56,600	154,400	47,700	3790	4100	12,620
Flash Point, °F(°C)	390(199)min	413(212)	423(217)	423(217)	460(238)	425(218)	375(191)
Pour Point, °F(°C)	-35(-37)max	-35(-37)	-28(-33)	-35(-37)	-65(-54)	-65(-54)	-45(-43)
Elemental Composition, wt%							
Barium		<0.015	0.13	< 0.001	0.79	<0.004	0.015
Calcium		0.40	0.39	0.02	< 0.001	0.22	0.01
Magnesium		0.002	0.004	0.060	Nil	0.011	Nil
Phosphorus		0.164	0.07	0.12	0.032	0.074	0.077
Sulfur		0.95	0.40	0.52	0.027	0.196	0.28
Zinc		0.14	0.08	0.18	<0.001	0.07	0.044

ND = Not Determined

G ATF	H ATF	I 10W/30	J HPTF	K HPTF	L OE/HDO-10	M 10W-30	N OE/HDO-10	O OE/HDO-10
6.74	7.90	11.65	9.61	6.46	6.69	11.25	6.57	6.07
36.42	43.27	69.17	60.85	43.91	44.49	73.48	43.92	38.39
5.9	6.4	9.3	7.9	6.2	6.6	9.3	ND	ND
and After Shear = 8.9 cSt								
1170	1570	2770	3000	2720	2390	3510	ND	ND
13,900	16,100	33,300	39,250	120,000	64,100	46,300	ND	ND
393(201)	415(213)	403(206)	430(221)	425(218)	415(213)	438(226)	420(216)	400(204)
-42(-41)	-29(-34)	-40(-40)	-27(-33)	-26(-32)	-25(-32)	-36(-38)	-18(-28)	-20(-29)
< 0.015	<0.015	<0.001	<0.015	<0.005	< 0.001	<0.005	< 0.005	<0.005
< 0.01	0.01	0.41	0.55	0.42	0.46	0.009	0.055	0.18
0.014	Nil	Nil	0.001	Nil	0.002	0.136	0.25	0.05
0.056	0.061	0.25	0.104	0.32	0.089	0.17	0.08	0.073
0.22	0.27	0.57	0.63	0.51	0.41	0.38	0.40	0.35
0.034	< 0.01	0.15	0.06	< 0.01	0.09	0.16	0.086	0.082

TABLE 6. RESULTS FOR JDM-J20A SPECIFICATION BENCH TESTS

Lubrication Code Description	Limit	A JD Ref	B OE/HDO-10	C 10W/30	D OEA
Water Sensitivity	Photo				
Sediment, vol%	0.1 max	0.10	0.10	0.03	0.02
Additive Loss, % max					
Calcium	15 max	15.0	9.1	5.0	None
Barium	15 max	None	14.3	None	6.3
Zinc	15 max	0	0	0	None
Phosphorus	15 max	0.6	2.9	0	3.0
Extreme Pressure, Timken					
Timken OK Load, lbf (N)	20(90) min	Pass	Pass	Pass	Fail
Timken Abrasion, scar dia, mm	Report	1.8	1.8	1.1	1.3
Mass Loss, mg	1.0 max	0.5	3.4	1.4	1.6
Contact Pressure, psi (Pa)	Report	6650(45.8)	2825(19.5)	4625(31.9)	3900(26.9)
Compatibility w/Rubber					
Vol Change, %	0 to +5	-0.56	-0.64	0.73	11.0
Hardness Change, pt duro	0 to -5	0.50	0.63	-0.70	-6.04
Precipitation	Tr, max	None	None	None	None
Compatibility w/Other Oils					
Additive Separation	None		None	None	None
Antifoam on 50/50 Blend					
Sequence I, ml	25 max		20	10	80
Sequence II, ml	50 max		35	20	50
Foam Break Time, s	30 max		9	10	15
Sequence III, ml	25 max		30	10	30
Oxidation on 50/50 blend					
New Blend 50/50 Visc @ 210°F (98.9°C), cSt	Report		8.06	10.06	7.56
Evaporation Loss, wt%	5 max		1.48	1.32	1.09
Visc @ 210°F (98.9°C), cSt	Report		8.13	10.11	7.87
Visc Increase @ 210°F (98.9°C), %	10 max		0.87	0.50	4.10
Sludge Formation	None		None	None	None
Additive Separation	Tr, max		None	None	None
Oxidation					
Vis @ 210°F (98.9°C), cSt	Report	10.90	1.76	10.39	6.24
Vis Increase @ 210°F (98.9°C), %	10 max	11.70	1.8	-0.9	1.6
Evaporation Loss, %	5 max	4.34	1.22	1.45	0.59
Sludge Formation	None	None	None	None	None
Additive Separation	Tr, max	None	None	None	None
Rust Protection	100 min	NR	NR	NR	NR
Copper Strip Corrosion	1B max	1A	1A	1A	1A
Antifoam					
Sequence I, ml	25 max	10	20	5	470
Sequence II, ml	50 max	20	100	40	65
Foam Break Time, s	30 max	12	38	17	17
Sequence III, ml	25 max	15	20	10	380

NR - No Rust.
Tr - Trace.

E OEA	F ATF	G ATF	H ATF	I 10W/30	J HPTF	K HPTF	L OE/HDO-10	M 10W/30
0.00	0.18	0.00	0.12	0.00	0.00	0.00	0.02	0.04
0	None	None	None	4.9	0	2.4	9.6	3.2
None	None	None	None	None	None	None	None	None
1.0	2.3	None	None	6.7	0	None	None	None
4.7	13.0	3.6	11.5	11.2	6.7	9.4	0.12	0.16
Fail	Fail	Fail	Fail	Pass	Pass	Fail	Pass	Pass
1.45	1.45	4.0	5.4	1.0	1.0	3.9	1.05	1.2
1.7	2.1	14.7	40.2	1.1	0.8	2.0	2.0	7.4
3500(24.2)	3500(24.2)	Failed	Failed	5075(35.0)	5075(35.0)	Failed	4825(33.3)	4225(29.2)
2.56	3.95	0.52	-0.4	-0.78	0.91	4.92	-1.77	-2.48
-1.93	-1.14	0.40	0.17	0.71	0.41	-0.63	0.05	-0.10
None	None	None	None	None	None	None	None	None
None	None	None	None	None	None	None	None	None
10	10	5	10	5	10	0	15	0
12	50	10	50	120	20	35	45	55
7	16	30	15	28	9	18	18	25
30	5	5	5	0	0	0	10	0
7.88	8.87	8.04	8.71	10.67	9.56	7.93	7.97	10.58
1.03	2.35	2.49	1.31	2.50	2.72	1.05	1.37	2.38
7.96	9.31	8.24	8.57	11.06	9.87	7.93	7.93	11.80
1.02	4.96	2.49	-1.6	3.66	3.24	0.00	-0.50	13.04
None	None	None	None	None	None	None	None	None
None	None	None	None	None	None	None	None	None
6.49	8.10	6.85	7.74	12.03	9.42	6.58	6.63	13.16
-0.6	-0.1	1.6	-2.03	3.26	-1.98	1.86	1.84	16.98
1.01	2.79	2.47	1.27	2.02	1.15	1.25	1.2	1.14
None	None	None	None	None	None	None	None	None
None	None	None	None	None	None	None	None	None
NR	NR	NR	NR	NR	NR	NR	NR	NR
1A	1A	4B	3B	1A	1A	1B	1A	1A
430	20	25	30	5	5	40	12	5
60	60	50	40	90	50	20	40	50
18	18	16	15	27	12	9	6	17
170	5	0	0	0	10	5	11	0

TABLE 7. OXIDATION AND EXTREME PRESSURE WEAR TEST RESULTS FOR LUBRICANTS CODES N AND O

Lubricant Code		A	N	O
Description		JD Ref	OE/HDO-10	OE/HDO-10
	Limit			
Oxidation				
K. Vis, 210°F (98.9°C), cSt	Report	10.90	6.63	6.14
Vis Increase @ 210°F(98.9°C), %	10 max	11.70	0.9	1.15
Evaporation Loss, %	5 max	4.34	1.6	0.49
Sludge Formation	None	None	None	None
Additive Separation	Tr, max	None	None	None
Extreme Pressure Timken				
Timken OK Load, lbf (N)	20(90) min	Pass	Fail	OK
Timken Abrasion, scar dia, mm	Report	1.8	1.6	1.0
Mass Loss, mg	1.0 max	0.5	1.4	1.7
Contact Pressure, psi	Report	6650	Fail	5924

failed the Sequence I category, while lubricant H was borderline. Lubricants F (ATF) and I (10W-30) failed the Sequence II category.

Compatibility With Other Oils--This test includes the performing of three separate tests on fresh 50/50 mixtures of test oil-reference oil; the tests are additive separation, antifoam, and oxidation (see Table 4). The test lubricants were quite compatible with the JD Ref fluid A. Only lubricant M (10W-30) failed the viscosity increase at 210°F (98.9°C) in the oxidation test, and was borderline in Sequence II antifoam category. Lubricant I (10W-30) failed the Sequence II antifoam category.

Compatibility With Rubber--This test uses the ASTM D 471 method with the modification that the test temperature shall be 100°±1°C (212°±1.8°F) and the rubber sample is immersed for a period of 70 hours using a specific rubber compound. Lubricants A (JD Ref), B (OE/HDO-10), D (OEA), I (10W-30), L (OE/HDO-10), and M (10W-30) did not pass the volume change percent, and lubricants A (JD Ref), B (OE/HDO-10), D (OEA), G (ATF), H (ATF), I (10W-30), and J (HPTF) did not pass the precipitation category of the test.

Copper Strip Corrosion--This test uses the ASTM D 130 method with the modification that the sample shall be heated for 3 hours at 300°F (148.9°C) in a temperature-controlled bath. Two automatic transmission fluids--G (ATF) and H (ATF)--did not pass this test, while all other lubricants did pass.

Extreme Pressure, Timken--This test uses the ASTM D 2782 method with the modification of cleaning the block and cup ultrasonically, and the masses of both are recorded. A load of 45 N (10 lbf) is applied and run for 6±0.1 hours. The block and cup are cleaned ultrasonically, and the mass loss is determined.

Of the 15 lubricants tested, lubricants A (JD Ref), I (10W-30), and J (HPTF) were the only lubricants which passed the complete test. These results are discussed further under the Transmission Final Drive Gear Wear section of this report.

Oxidation--A watch glass covered lubricant sample in a glass beaker is stored in a ventilated oven at 300°±5°F (149°±2.7°C) for 100 hours. After these hours, the evaporation loss is determined at 99°C (210°F) and reported as percent increase based on the new lubricant viscosity. The sample is also observed for sludge formation and additive separation. Of the 15 lubricants, oil A (JD Ref) and oil M (10W-30) failed in viscosity increase with all oils passing in all the other performance categories.

Rust Protection--This test uses the ASTM D 1748 method with the modification that SAE 1010 cold rolled steel is used for the panels; it is ground on two sides with 10-20 microinch (0.25-0.50 micrometer) rms finish. The panels are immersed in boiling naphtha, dipped in boiling methanol, and then soaked in the test lubricant. The panels are drained and suspended in a humidity cabinet for a minimum of 100 hours. The rust protection test is the only bench test that every lubricant passed.

Water Sensitivity--A small percentage of deionized water is added to the candidate lubricant, mixed in a blender, and stored in a centrifuge tube in a light-tight chamber for 7 days. The sample is again centrifuged, and the percent by volume of sediment is reported with a metallic analyses of the additive in the top oil phase. Of the 13 lubricants tested, only two--F (ATF) and H (ATF)--did not pass all phases of the test, and these lubricants failed only the sediment category.

Friction and Wear--The Army strives to use different lubricants in more than one application. Such multipurpose applications include use of OE/HDO-10 and

arctic engine oils (OEA) in power steering pumps, automotic/power-shift transmission and other uses. Therefore, near the completion of the testing, three lubricants A (JD Ref), D (OEA), and L (OE/HDO-10) were selected for testing in the Caterpillar TO-2[10] and Detroit Diesel Allison C-3[11] tests (see Table 8). The results from the TO-2 test show good (passing) performance was obtained with military lubricants D (OEA) and L (OE/HDO-10) with a 7.14- and 13.2-percent increase in stopping time and an average wear of 0.0028 (0.07112 mm) and 0.0064 in. (0.16256 mm) for the bronze discs and 0.0024 (0.06096 mm) and 0.0034 in. (0.08636 mm) for the steel plates. However, lubricant A (JD Ref) failed with a 25-percent increase in stop time but showed acceptable performance in average wear of 0.0057 in. (0.14478 mm) on the bronze discs and 0.0036 in. (0.09144 mm) on the steel plates. These results are shown graphically in Appendix C.

TABLE 8. FRICTION-WEAR TEST RESULTS FOR LUBRICANTS CODES D AND L USING CATERPILLAR TO-2 AND ALLISON C-3 TESTS

Lubricant Code Description	Limit	A JD Ref	D OEA	L OE/HDO-10
1. Caterpillar TO-2 Test				
Slip Time, % Increase	15 max	25	7.1	13.2
Bronze Disc Wear, in.x 10^{-3} (mm)	10 (0.25)max	5.7(0.14)	2.8(0.07)	6.4(0.16)
Steel Plate Wear, in.x 10^{-3} (mm)	4 (0.10)max	3.6(0.09)	2.4(0.06)	3.4(0.09)
2. Allison C-3 Test				
Slip Time @ 5500 cycles, s	0.85 max	0.99	0.72	0.79
Torque @ 0.2 s slip Time @ 5500 lb-ft	75 min	55	105	90
Torque Diff @ 0.2 s Slip Time (5500-1500) lb-ft	30 max	49	9	24

The results from the Allison C-3 test showed good performance in all three of the test categories for the military lubricants D (OEA) and L (OE/HDO-10). First, the maximum slip time after 5500 cycles was less than 0.85 seconds (0.72 and 0.79 seconds were obtained); second, the torque at 0.2 seconds slip time at 5500 cycles was greater than 75 lb-ft (105 and 90 lb-ft were obtained); third, the difference in torque at 0.2 seconds slip time between 1500 and 5500 cycles must not exceed 30 lb-ft (9 and 24 lb-ft were obtained).

Lubricant A (JD Ref) failed all three categories of the C-3 test. These results are shown graphically in Appendix C.

C. Full-Scale Performance Tests

In this program, two of the main areas of concern were (1) the potential gear wear in the transmission final drive and (2) friction performance in the wet-brakes in the John Deere 410 front loader/backhoe. As noted earlier, concern for unacceptable HPTF system performance when using MIL-L-2104C oils was expressed by industry representatives--particularly in the areas of wear and wet brake chatter. These areas of concern are discussed below.

Wet-Brake Chatter and Capacity--As is well known, wet-brake or wet-clutch chatter is a stick-slip phenomenon experienced under boundary layer lubrication conditions due to unacceptable frictional characteristics in the lubricant/friction-material system. Generally, a high dynamic coefficient of friction at low sliding speeds leading to a high static coefficient of friction results in the chatter phenomenon. Excessive chatter leads to severe vibration/noise, ablation of the friction material surface, slippage/excess heat build-up, and eventual failure. However, a definition for excessive chatter is difficult to quantify. Insufficient brake capacity results in excessive brake slippage, heat build-up, and frictional failure. The JD wet-brake chatter and capacity tests were performed simultaneously with the chemical/physical property and bench tests. These tests were performed on all lubricants except N (OE/HDO-10) and O (OE/HDO-10). The results obtained are shown in Figure 2 and Appendix D. This test was conducted in accordance with the procedures given in Appendix A. The results for the reference fluid are bounded by the shaded area and

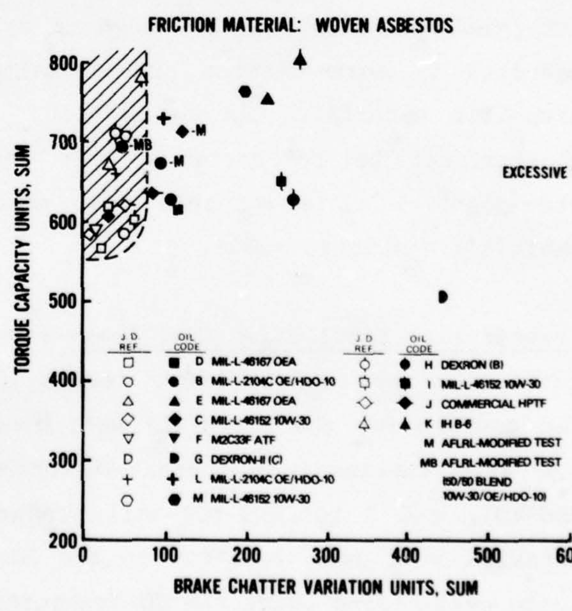


FIGURE 2. PERFORMANCE OF REFERENCE, ARMY AND COMMERCIAL LUBRICANTS IN JOHN DEERE LABORATORY WET-BRAKE TEST

use the open symbols in Figure 2. Only lubricant C (10W-30), with 33 chatter units, fell within the limits (6 to 74 units) bounded by Reference fluid A. No additional work was done with this lubricant because no more oil could be obtained after exhausting the AFLRL supply. Four other lubricants--B (OE/HDO-10), D (OEA), J (HPTF), and L (OE/HDO-10)--did fall outside the boundary of the Reference fluid A, but were considered to be acceptable. The best Army lubricant tested was lubricant L (OE/HDO-10) with a chatter sum of 101 units.

A modified Army wet-brake test was also used wherein the new friction pads and discs are installed but preconditioning with the reference fluid is omitted. Instead, the test oil is the only lubricant to be used on the wet-brake components. This modified test would relate to Army Depot rebuilt tractors, wherein only the Army's lubricant would be used. For this program, three of these AFLRL-modified wet-brake tests were run, using lubricants B (OE/HDO-10), C (10W-30), and a 50/50 blend of B and C. Lubricants B and C fell just outside the area bounded by the JD Ref fluid, while the 50/50 blend fell within the bounded zone in Figure 2, indicating a synergistic effect. After testing thirteen lubricants, it was learned that the John Deere 410 tractor uses graphitic brake pad friction material while the JDM-J20A wet-brake test uses asbestos friction material. Therefore, further laboratory wet-brake chatter and capacity testing was discontinued. No correlation between the asbestos and graphitic materials is known to exist. However, it is believed that the asbestos is more chatter prone/sensitive, and hence more severe than the graphitic material. In any event, it is not known what level of continuous chatter can be tolerated in this equipment from a reliability/durability standpoint. It is possible that moderate chatter detracts only from the vehicle's aesthetic value.

Transmission Final Drive Gear Wear--From the previously discussed data, six lubricants were selected for testing in the transmission final drive test. The concern for the potential wear problem stemmed from the fact that, of the six Army lubricants selected--D (OEA), L (OE/HDO-10), M (10W-30), N (OE/HDO-10), and O (OE/HDO-10)--all produced inferior performance in the Timken abrasion wear test relative to the JD Ref fluid. However, in all six full-scale evaluations using the JD Transmission final drive gear wear test, it was found that the Army's lubricants produced less gear wear than the JD Ref fluid. These results can be seen in Tables 9 and 10. Table 9 shows the

TABLE 9. TRANSMISSION FINAL DRIVE TEST

Lubricant		Wear, in. x 10^{-3} (mm)			
		Left Hand		Right Hand	
Code	Description	JD	Candidate	JD	Candidate
D	OEA	3(0.08)	0.9(0.02)	2.3(0.06)	1.0(0.03)
I	10W/30	3.9(0.1)	0.8(0.02)	3.3(0.08)	0.8(0.02)
L	OE/HDO-10	3.5(0.09)	2.3(0.06)	3.2(0.08)	2.9(0.07)
M	10W/30	3.4(0.09)	1.2(0.03)	3.2(0.08)	1.3(0.03)
N	OE/HDO-10	2.9(0.07)	0.8(0.02)	3.0(0.08)	0.9(0.02)
O	OE/HDO-10	2.8(0.07)	0.7(0.02)	2.8(0.07)	0.8(0.02)

TABLE 10. RELATION OF TIMKEN WEAR TEST AND JDM-J20A FINAL DRIVE WEAR USING MILITARY ENGINE OILS

Lubricant		Timken Abrasion Test				Final Drive Combined Wear,
Code	Description	OK Load	Scar, mm	Mass Loss, mg	Contact Pressure, psi	in.x10^{-3} (mm)
A	JDM-J20A Ref	Pass	1.8	0.5	6650	6.2*(0.16)
D	MIL-L-46167 OEA	Fail	1.3	1.6	3900	1.9(0.05)
I	MIL-L-46152 10W-30	Pass	1.0	1.1	5075	1.6(0.04)
B	MIL-L-2104C Ref OE/HDO-10	Pass	1.05	2.0	4825	5.2(0.13)
M	MIL-L-46152 10W-30	Pass	1.2	7.4	4225	2.5(0.06)
N	MIL-L-2104C OE/HDO-10	Fail	1.6	1.4	----	1.7(0.04)
O	MIL-L-2104C OE/HDO-10	Pass	1.0	1.7	5924	1.5(0.04)
Test Requirements		20 min	Report	1.0 max	Report	≤ Ref

* Average combined (LH & RH) wear for six tests

results for the individual left side (LH) and right side (RH) gear wear. After the first 50-hour test using the JD reference oil is completed, the drive gears are removed, measured, and reinstalled in the opposite wheel. This procedure ensures that each gear is loaded on a different side of the gear tooth during the second 50-hour test, in which the test lubricant is used. Table 10 compares the combined final drive wear (LH plus RH) for each test oil and the six-test average for the JD Ref fluid with results from the Timken abrasion test. Note the lack of correlation between the bench wear test and the full-scale test.

PTO Clutch Stall and Breakaway--Four lubricants--D (OEA), I (10W-30), L (OE/HDO-10), and M (10W-30)--were tested before it was learned that the John Deere 410 tractor did not have a PTO clutch. Therefore, this test was also discontinued. Incidentally, the only lubricant passing all requirements of this test was lubricant L (OE/HDO-10) as shown in Table 11.

TABLE 11. JDM-J20A SPECIFICATION PTO* CLUTCH STALL AND BREAKAWAY TESTS

Test Description	Limit	Lubricant Code/Description: D OEA	I 10W-30	L OE/HDO-10	M** 10W-30
Stall	OK	OK	OK	OK	Fail
Coef of Friction	0.080	OK	0.0745	OK	0.0764
Gear Wear, in.x10^{-3} (mm)					
Front	8(0.20)	14.3(0.36)	11.6(0.29)	6.7(0.17)	15.6(0.40)
Back	8(0.20)	14.5(0.37)	1.9(0.05)	7.5(0.19)	15.9(0.40)

* Power Take-off.

** Stopped test at 1000 cycles.

All the laboratory test results pertaining to this military tractor are shown in Table 12. This table is a summary of the overall test results, ranking or grading the lubricants in terms of pass, fail, or borderline performance.

TABLE 12. OVERALL PERFORMANCE OF ARMY LUBRICANTS

Lubricant Code	A	B	C	D	E	I	L	M	N	O
Description	J D Ref	OE/HDO-10	10W/30	OEA	OEA	10W/30	OE/HDO-10	10W/30	OE/HDO-10	OE/HDO-10
Test Requirements										
K. Viscosity, cSt										
New Oil at 210°F (98.9°C)	P	F	P	F	F	P	F	P	F	F
Viscosity Loss at 210°F (98.9°C) after sonic shear	P	F	P	F	F	P	F	P	ND	ND
Brookfield Vis, cP/m Pas•s										
at 0°F(-17.8°C)	P	P	P	P	P	P	P	P	ND	ND
at -30°F (-34.4°C)	P	F	P	P	P	P	P	P	ND	ND
Flash Point, °F (°C)	P	P	P	P	P	P	P	P	P	P
Pour Point, °F (°C)	P	F	P	P	P	P	F	P	F	F
Water Sensitivity										
Sediment, vol %	P	P	P	P	P	P	P	P	ND	ND
Additive loss, % max										
Calcium	P	P	P	P	P	P	P	P	ND	ND
Barium	P	P	P	P	P	P	P	P	ND	ND
Zinc	P	P	P	P	P	P	P	P	ND	ND
Phosphorus	P	P	P	P	P	P	P	P	ND	ND
Extreme Pressure, Timken										
Timken OK Load, lbf (N)	P	P	P	F	F	P	P	P	F	P
Timken Abrasion, scar dia, mm	R	R	R	R	R	R	R	R	R	R
Mass Loss, mg	P	F	BL	F	F	P	F	F	BL	F
Contact Pressure, psi (Pa)	R	R	R	R	R	R	R	R	R	R
Compatibility w/Rubber										
Vol Change, %	F	F	P	F	P	F	F	F	ND	ND
Hardness Change, pt duro	F	F	P	F	P	F	F	P	ND	ND
Precipitation	P	P	P	P	P	P	P	P	ND	ND
Compatibility w/Other Oils										
Additive Separation	ND	P	P	P	P	P	P	P	ND	ND
Antifoam on 50/50 Blend										
Antifoam, Sequence I, ml	ND	P	P	BL	P	P	P	P	ND	ND
Antifoam, Sequence II, ml	ND	P	P	P	P	F	P	BL	ND	ND
Foam Break Time, s	ND	P	P	P	P	P	P	P	ND	ND
Antifoam, Sequence III, ml	ND	P	P	BL	BL	P	P	P	ND	ND
Oxidation on 50/50 Blend										
New Blend 50/50 Vis at 210°F (98.9°C)	ND	R	R	R	R	R	R	R	ND	ND
Evaporation Loss, wt %	ND	P	P	P	P	P	P	P	ND	ND
Vis at 210°F (98.9°C)	ND	R	R	R	R	R	R	R	ND	ND
Vis Increase at 210°F (98.9°C), %	ND	P	P	P	P	P	P	F	ND	ND
Sludge Formation	ND	P	P	P	P	P	P	P	ND	ND
Additive Separation	ND	P	P	P	P	P	P	P		
Oxidation										
Vis at 210°F (98.9°C)	R	R	R	R	R	R	R	R	R	R
Vis Increase at 210°F (98.9°C), %		P	P	P	P	P	P	F	P	P
Evaporation Loss, %	P	P	P	P	P	P	P	P	P	P
Sludge Formation	P	P	P	P	P	P	P	P	P	P
Additive Separation	P	P	P	P	P	P	P	P	P	P
Rust Protection	P	P	P	P	P	P	P	P	ND	ND
Copper Strip Corrosion	P	P	P	P	P	P	P	P	ND	ND
Antifoam										
Sequence I, ml	P	P	P	F	F	P	P	P	ND	ND
Sequence II, ml	P	F	P	F	F		P	P	ND	ND
Foam Break Time, s	P	F	P	P	P	P	P	P	ND	ND
Sequence III, ml	P	P	P	F	F	P	P	P	ND	ND
Transmission Final Drive Wear										
Left hand, in. (mm)	P	ND	ND	P	ND	P	P	P	P	P
Right hand, in. (mm)	P	ND	ND	P	ND	P	P	P	P	P
Caterpillar TO-2										
Slip Time, % increase	F	ND	ND	P	ND	ND	P	ND	ND	ND
Bronze Disc Wear, in. (mm)	P	ND	ND	P	ND	ND	P	ND	ND	ND
Steel Plate Wear, in. (mm)	P	ND	ND	P	ND	ND	P	ND	ND	ND
Allison C-3										
Slip Time at 5500 cycles, s	F	ND	ND	P	ND	ND	P	ND	ND	ND
Torque at 0.2 s Slip Time at 5,500 (lb-ft)	F	ND	ND	P	ND	ND	P	ND	ND	ND
Torque Diff at 0.2 s Slip Time at 5500-1500 (lb-ft)	F	ND	ND	P	ND	ND	P	ND	ND	ND

P = Pass BL = Borderline F = Fail ND = Not Determined R = Report, No Limits

D. Field Measurements/Long-Term Effect

The use of asbestos material in the JDM-J20A wet-brake test rather than the graphitic material used in the John Deere 410 tractor resulted in a need to make actual in-vehicle wet-brake chatter tests. After evaluating the previous compiled data, MIL-L-2104C OE/HDO-10 lubricant L appeared to be almost as good in some areas and better in others than the JD Ref fluid A. Lubricants L, D (OEA), I (10W-30), M (10W-30), N (OE-/HDO-10), and O (OE/HDO-10) were selected as possible compromise lubricants to be evaluated in the actual John Deere 410 tractor. The test procedure, detailed in Appendix B, included recording brake chatter measurements while operating the vehicle in tight left and right turns and checking for total hydraulic performance. It can be seen in Table 13 that lubricant L (OE/HDO-10) performed as well or better than the JD Ref fluid A.

TABLE 13. FIELD BRAKE-CHATTER RATING OF ARMY ENGINE OILS IN JOHN DEERE MODEL 410 TRACTORS

Lubricant		JD-410	Chatter Rating*
Code	Description	Vehicle+	New Oil
A	JDM-J20 Ref Oil	FB	128
D	MIL-L-46167 OEA	FB	187
I	MIL-L-46152 10W-30	FB	191
L	MIL-L-2104C Ref OE/HDO-10	FB	120
N	MIL-L-2104C OE/HDO-10	FSH	161
O	MIL-L-2104C OE/HDO-10	FSH	188
L	MIL-L-2104C Ref OE/HDO-10	FSH	137
A	JDM-J20A Ref Oil	FSH	134
L	MIL-L-2104C Ref OE/HDO-10	FH	128

* Rating is sum of LH and RH brakes at two different temperatures-- zero equals no chatter -- brake facings are molded graphite.

\+ FB = Ft. Belvoir, VA.
FH = Ft. Hood, TX, C Company.
FSH = Ft. Sam Houston, TX.

Long-Term Vehicle Effects--In-vehicle wet-brake chatter, durability, and overall hydraulic performance tests were initiated to establish long term effects of Army lubricant L (OE/HDO-10) in the John Deere 410 tractor. This lubricant was selected due to its overall good performance in the JDM-J20A specification tests and its availability as a contract/fielded product.

The in-vehicle lubricant evaluations are being conducted at Ft. Sam Houston and Ft. Hood, Texas in accordance with the procedure described in Appendix B.[14,15] One vehicle is being monitored at Ft. Sam Houston, and there have been several hydraulic system problems; however, none of these problems was determined to be lubricant related. Three vehicles are being monitored at Ft. Hood. One is a control vehicle using the JD Ref fluid A since July 1978 and having accumulating 212 hours of service, and two are test vehicles using the OE/HDO-10 lubricant L; one since July 1978 which has accumulated 169 hours of service, and the second just initiated in March 1979. Of the two tractors on test since July 1978, the tractor using the A (JD Ref) fluid has had no lubricant-related problems, while the other tractor using the L (OE/HDO-10) lubricant has had one hydraulic system problem which was determined not to be lubricant-related.

IV. CONCLUSIONS

General conclusions from this work are as follows:

(1) The Army engine oils produce superior water sensitivity performance compared with the JD Ref oil A; this is believed due to the formulation technology used for compounding the engine oils.

(2) The Army OE/HDO-10 lubricants do not meet the new oil minimum viscosity requirement; however, the OE/HDO-10 oils do not undergo permanent viscosity loss in the sonic shear test, unlike the JD Ref oil or the Army 10W-30 multigrade oils, which contain shear sensitive viscosity index (VI) improvers. Further, the Army OE/HDO-10 lubricants would not be expected to undergo permanent viscosity loss in more important mechanical shear systems like hydraulic pumps and gears drives. Such VI-improved oils (i.e., JD Ref and 10W-30), however, would be expected to undergo permanent viscosity loss in mechanical shear.

(3) Fresh-oil viscosity has no apparent effect on overall gear wear performance, because all the OE/HDO-10 lubricants produced less gear wear than the more viscous JD Ref oil A.

(4) Contrary to expectations, performance in final drive gear wear test is not predicted by lubricant performance in Timken abrasion test. As shown in Table 10, every Army oil produced superior gear-wear performance but inferior Timken Abrasion Mass Loss and contact pressure in comparison to the JD Ref oil; therefore, there is no true correlation between the Timken and gear wear tests.

(5) Army OE/HDO-10 lubricants produce superior oxidation performance relative to the JD Ref oil A. This oxidation performance is also believed to be due to the formulation requirements for engine oils.

(6) No correlation of additive chemistry with fluid performance is evident.

(7) The qualified/fielded MIL-L-2104C OE/HDO-10 lubricant L is judged to be equal to the equipment supplier's reference oil in overall performance.

Some specific conclusions are also drawn:

(1) The qualified/fielded MIL-L-2104C OE/HDO-10 lubricant L has been found to perform as well as the Reference Fluid A in actual vehicle chatter tests.

(2) Army MIL-L-46152 (10W-30) lubricant C produced equal or superior performance relative to the reference oil in all areas tested.

(3) Army MIL-L-46167 synthetic arctic engine oil D produced generally acceptable overall performance in the specification tests; its oxidation and wear performance are superior, while seal swell, foam, and brake chatter performance are not as good as the reference oil A. Concern for seal and foam performance was noted in earlier work[16,17], but significance of poor performance in these two areas

is unknown due to lack of correlation with any field problems. In fact, this OEA product has obtained an excellent field history to date in regular arctic service since 1969 and in an outside arctic pilot fleet test since 1977.

(4) Commercial fluid J is an overall good performer in all areas tested; however, this lubricant is not suited for engine usage, but its use in Army CCE HPTF systems would create a viable alternate to the JD proprietary fluid.

V. RECOMMENDATIONS

The recommendations made as a result of this work are:

(1) Army engine oils of the type tested herein should be evaluated in extended versions of the critical JD specification performance tests.

(2) If new John Deere vehicles are procured in the future, the MIL-L-2104C OE/HDO-10 lubricant L should be installed as a factory-fill fluid in a number of vehicles and closely monitored for overall field performance. Likewise, a number of new vehicles should be required to use other MIL-L-2104C OE/HDO-10 products found in the supply system and closely monitored for overall performance.

(3) Based on indications of successful usage of Army engine oils in the laboratory and field testing noted in items (1) and (2), across the board use of the Army engine oils should be recommended for John Deere CCE HPTF systems.

(4) These Army engine lubricants should be subjected to other hydraulic/power transmission system/component testing to establish their suitability for use in broader applications, i.e., for use in other brands of CCE.

(5) Additional research and development should be conducted to establish HPTF system/component requirements for possible inclusion in the

MIL-L-2104 specification (similar to what is already included in the MIL-L-46167 specification for year-around HPTF system usage). No doubt this will require development of additional or modification of existing universal performance test procedures.

VI. LIST OF REFERENCES

1. Lt. Col. Thomas A. Stumm, "The U.S. Army Commercial Construction Equipment System Plan," SAE Paper No. 710506, Peoria, Illinois, April 1971.

2. Military Standard 838B, "Lubrication of Military Equipment," 7 September 1975.

3. U.S. Military Specification, MIL-L-46167, Lubricating Oil, Internal Combustion Engine, Tactical Service, November 1970.

4. U.S. Military Specification, MIL-L-46167, Lubricating Oil, Internal Combustion Engine, Arctic, February 1974; Amendment 1, May 1978.

5. ASTM Minutes Committee D-2, Technical Div. B Section II, Automatic Transmission Fluids, November 21, 1974.

6. Letter, MERADCOM, STSFB-GL, ASTM D2, Technical Div. B-II, Automatic Transmission Fluids, 13 August 1974.

7. Specification JDM-J20A, Transmission and Hydraulic Oil, John Deere Product Engineering Center, Waterloo, Iowa, September 1975.

8. U.S. Military Specification MIL-L-46152, Lubricating Oil, Internal Combustion Engine, Administrative Service, November 1970.

9. "DEXRON Automatic Transmission Fluid Specification," Fuels and Lubricants Department, General Motors Research Labs, Warren, Michigan, 1967.

10. "DEXRON-II Automatic Transmission Fluid Specification," Fuels and Lubricants Department, General Motors Research Labs, Warren, Michigan, July 1973.

11. "Ford Automatic Transmission Fluid Specification M2C33-G," Ford Motor Co., Dearborn, Michigan, December 1972.

12. "Oil Test TO-2," Caterpillar Tractor Co., Peoria, Illinois, 10 July 1974.

13. "Allison Type C-3 Hydraulic Transmission Fluid Specification," Allison Division, General Motors Corp., Indianapolis, Indiana, 8 February 1977.

14. Letter, MERADCOM, DRDME-GL, 63rd Engineering Detachment (Utilities) Fort Sam Houston, Texas, 20 December 1977.

15. Letter, MERADCOM, DRDME-GL, 62nd Engineering Construction Battalion, Fort Hood, Texas, 15 February 1978.

16. "Compatibility of Military Engine Oils With Hydraulic and Power Transmission Fluid Systems (HPTF)," AFLRL Final Letter Report No. 38, File H4-2473, 6 May 1974.

17. Lestz, S.J., P.D. Hopler, and T.C. Bowen, "Performance of Army Arctic Engine Oils in Hydraulic and Power Transmission Fluid Systems," Interim Report AFLRL No. 74, AD A019524, September 1975.

18. Hopler, P.D. and S.J. Lestz, "Application of Synthetic Engine Oils in Army Hydraulic and Power Transmission Fluid Systems," SAE Paper No. 750828, Milwaukee, Wisconsin, September 1975.

APPENDIX A
WET-BRAKE TEST PROCEDURES

A. John Deere Wet-Brake Test Procedure

The wet-brake is rebuilt prior to each test, and uses new friction elements for each test (i.e., brake pads and disc).

Break-in and preconditioning is initially performed with JD Ref specification fluid. After break-in is completed, friction characteristics are determined for use as a reference base line.

The John Deere fluid is then drained and the system flushed and refilled with the candidate fluid.

The John Deere Wet-Brake Test is then performed. Concurrently, the friction characteristics are determined and compared to those obtained under above paragraph on break-in and preconditioning.

B. AFLRL "Modified" Wet-Brake Test Procedure

The lubricants used in this test were subjected to the wet-brake test described in Section A with the following modification:

> Instead of the break-in and preconditioning with JD Ref fluid, that portion of the test is performed with a fresh sample of the candidate fluid; that is, the friction elements never "see" the JD Ref oil; no flush is employed.

APPENDIX B
TEST PROCEDURE FOR EVALUATING IN-VEHICLE
WET-BRAKE CHATTER AND EXTENDED-USE PERFORMANCE

Evaluation of the MIL-L-2104C OE/HDO-10 Army Reference Lubricant in John Deere CCE Hydraulic and Power Transmission Fluid System

Scope

The MIL-L-2104C OE/HDO-10 lubricant previously found to be as good or better than the JD lubricant in the JDM-J20A specification laboratory and field testing will be utilized in an Army John Deere Model 410 front loader/backhoe to compare extended-use performance of this OE/HDO-10 with the factory fill/service fill fluid.

Test Lubricants

1. John Deere factory fill/service fill oil (this is the reference oil).

2. MIL-L-2104C OE/HDO-10, MIL-L-46152, and MIL-L-46167 products obtained from government supply system (to be furnished by MERADCOM/AFLRL).

Test Course

It is required to operate the vehicle in a test area in the absence of commercial traffic. Space is needed to turn vehicle in tight turns. Both gravel/dirt and paved surfaces are required.

Method of Test*

1. Install front loader cylinder blocks.

2. Install backhoe cylinder locks.

3. Install vibration pick-up on rear axle housing and temperature recorder in transmission dip stick (provided by AFLRL).

4. Drive the vehicle through a designated course requiring several tight left and right turns. Measurements of chatter and temperature should be made during these turns.

5. Vehicle performance is observed in vehicle drivability and the hydraulic system operability.

6. Obtain a 4- to 6-oz sample of warm hydraulic system oil from each vehicle using a suction tube and plastic bottle. This will be a before-test sample.

7. Drain the used oil from the complete hydraulic and power transmission system.

8. Install a fresh charge of JD factory fill or MIL-L-2104C (MC-606) oil as a flush.

*The in-vehicle wet-brake chatter test includes only Steps 1 through 13.

9. Warm up vehicle engine and hydraulic system.

10. Drain the flush oil from the system and replace the filters.

11. Install a fresh charge of JD factory fill or MIL-L-2104C (MC-606) lubricant and ensure system is full.

12. Operate the vehicle through a designated course requiring several tight left and right turns (same as Steps 4 and 5). The chatter/vibration and temperature should be recorded during these turns.

13. Obtain a 4- to 6-oz sample of the warm hydraulic oil from the vehicle as described in Step 6.

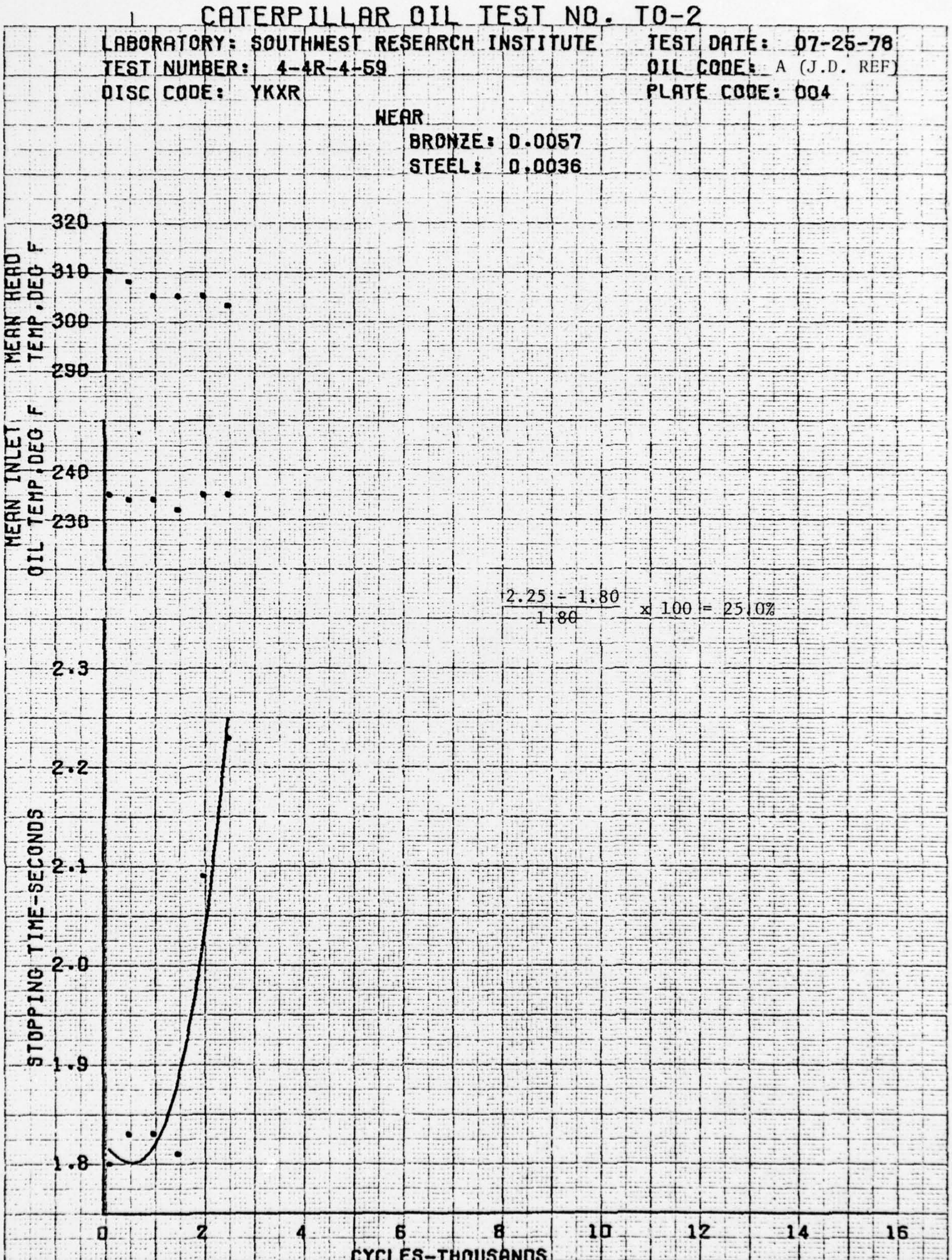
14. Continue to obtain a sample every six weeks, or as deemed necessary to properly monitor the lubricants for the duration of the test (minimum of twelve months).

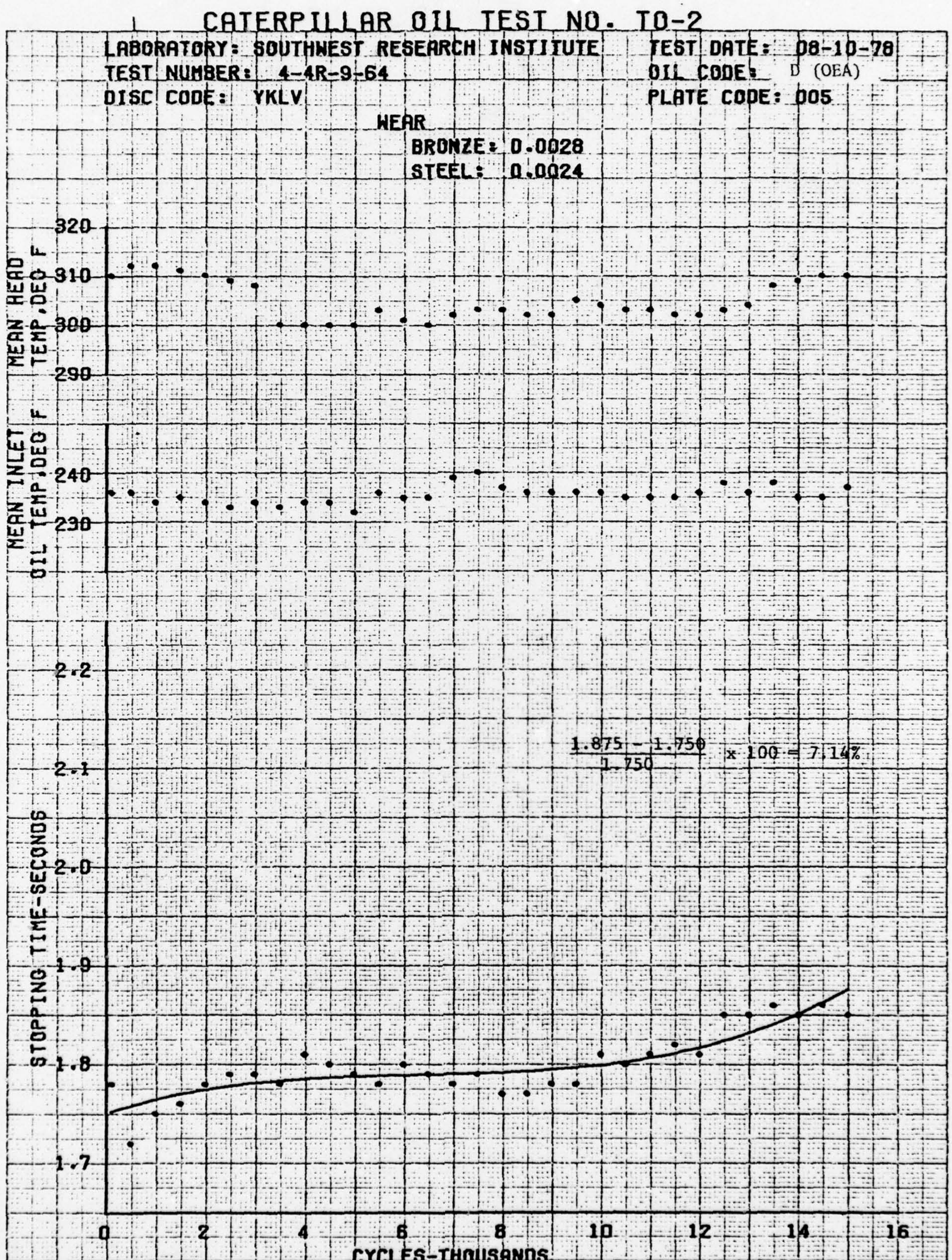
15. Every twelve weeks the vibration pick-up and temperature recorder will be reinstalled by MERADCOM/AFLRL personnel, and the chatter and temperature recorded as described in Step 12.

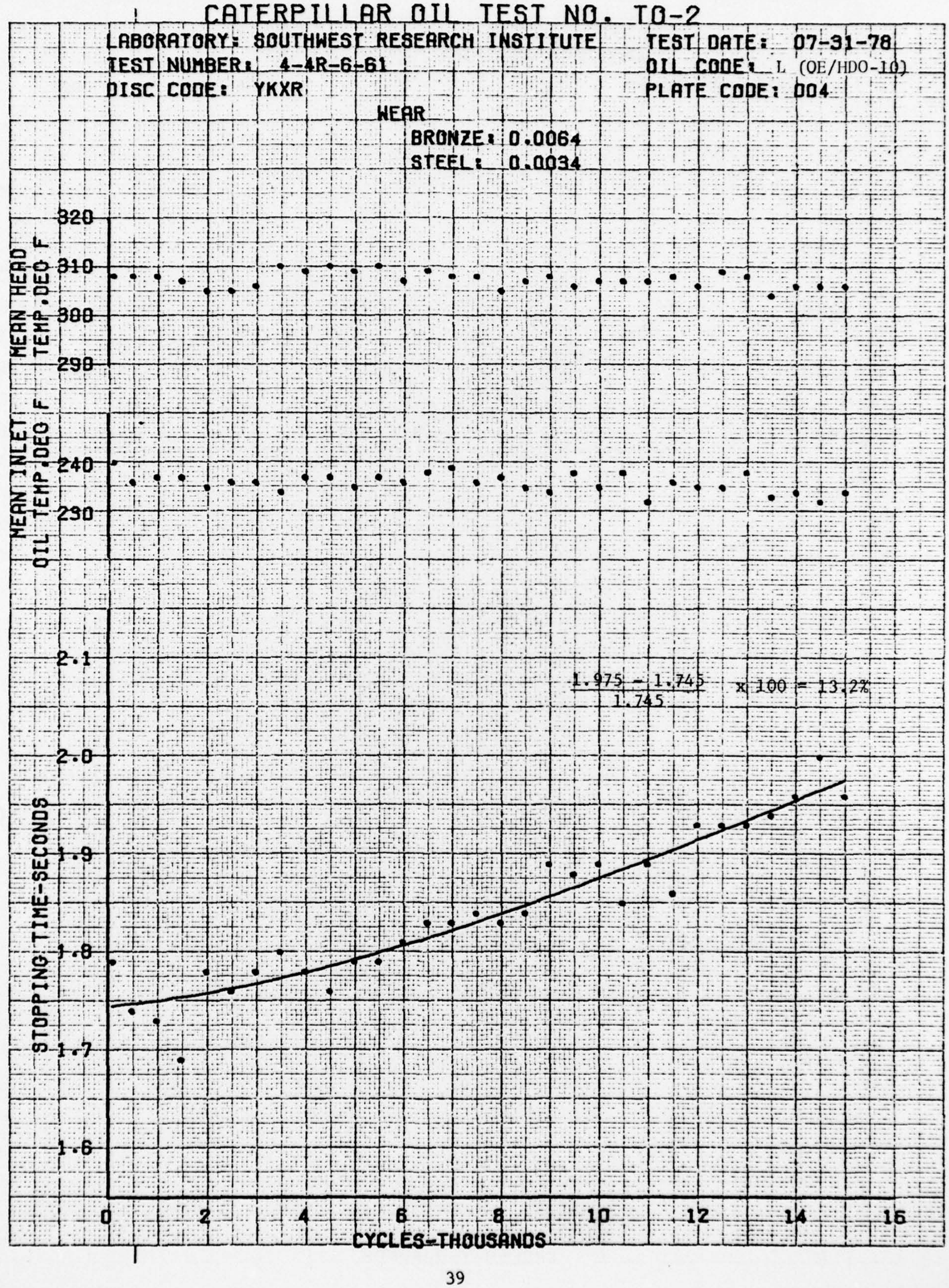
APPENDIX C

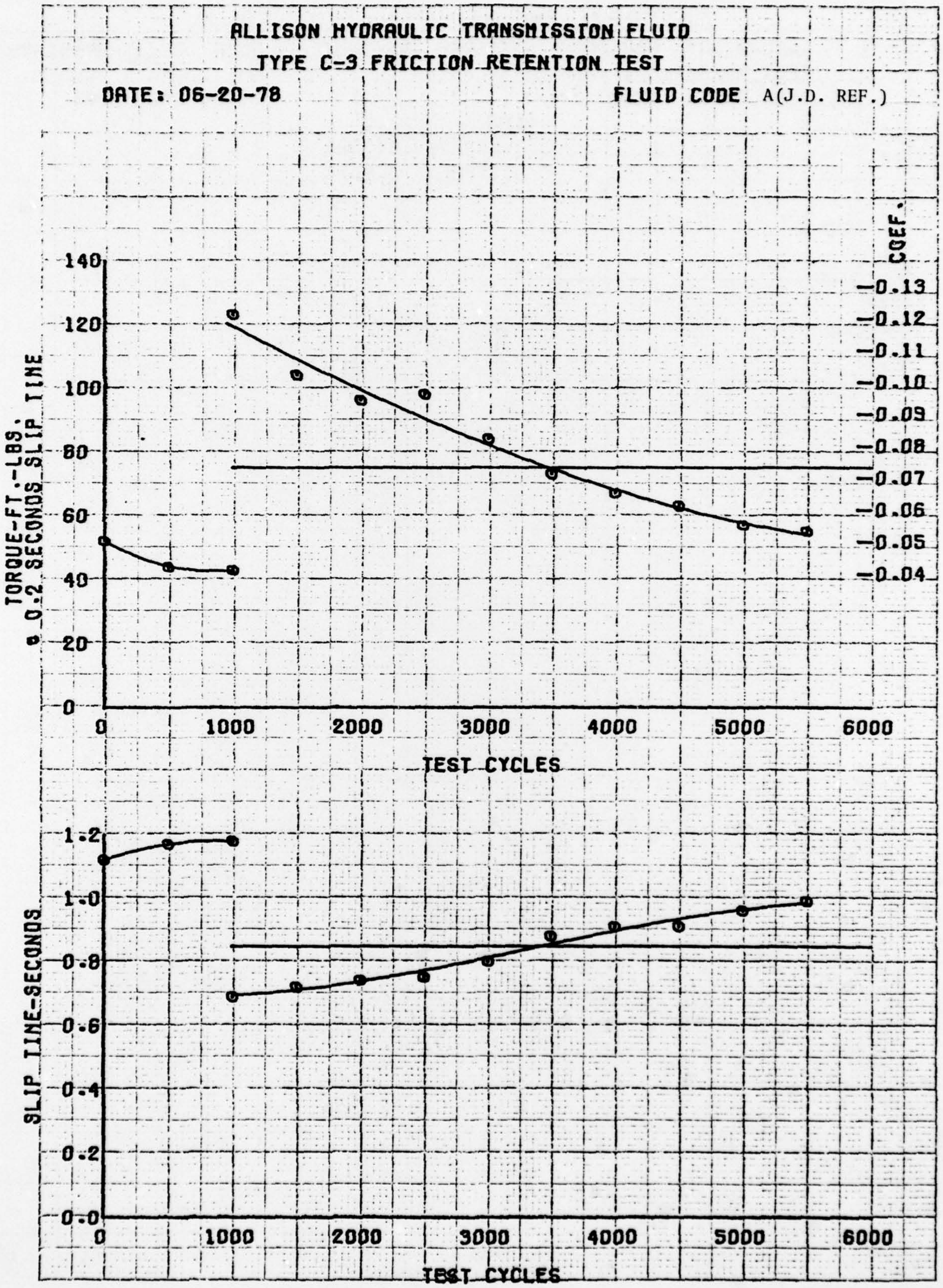
FRICTION-WEAR BENCH TESTS

For this program, three lubricants were selected for testing in the Caterpillar TO-2 and the Detroit Diesel Allison C-3 tests. The results of these tests are shown graphically in the following six figures, pages 37-43 and are discussed in pages 19-21 of the text.

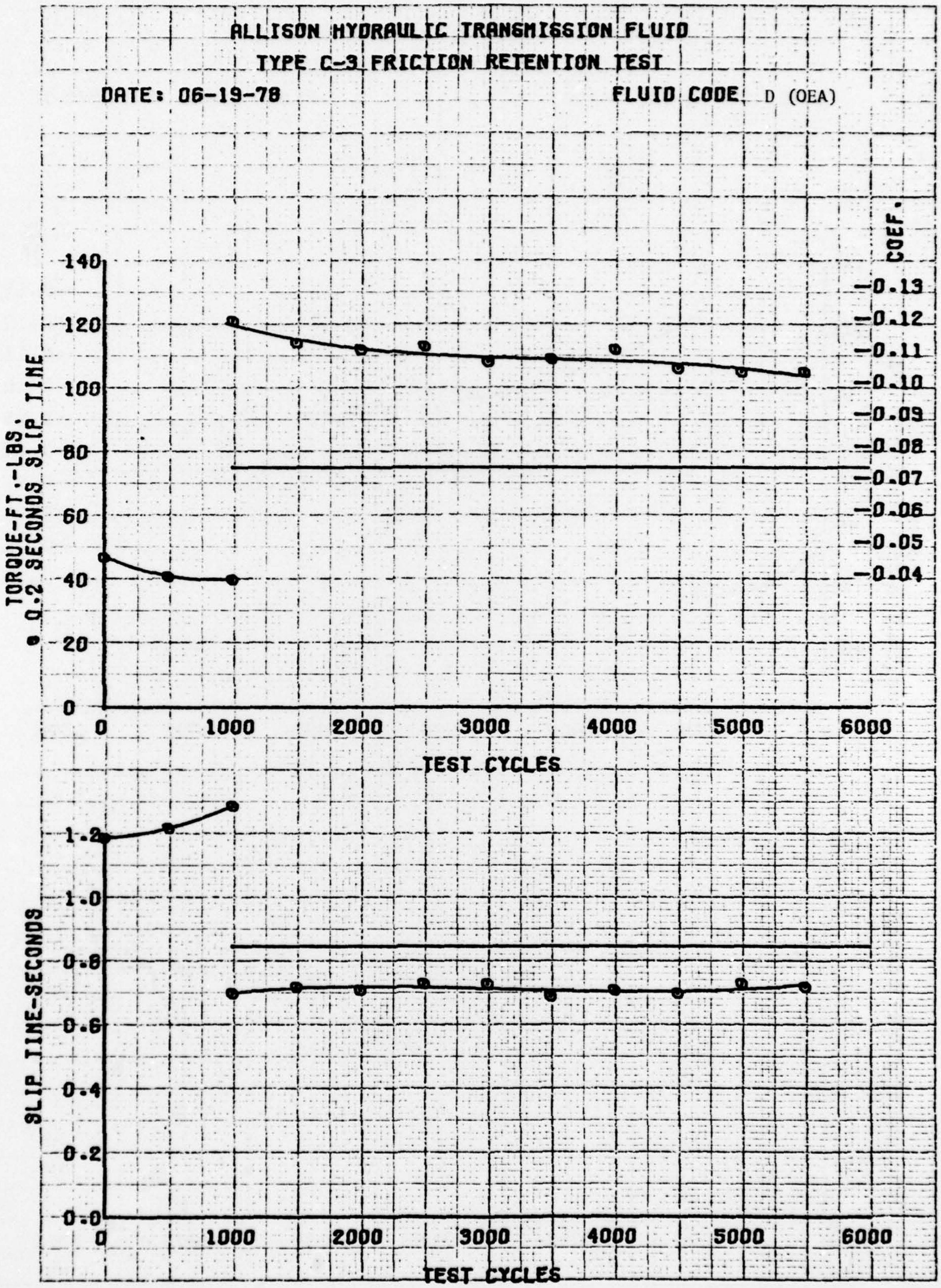

CATERPILLAR OIL TEST NO. TO-2
LABORATORY: SOUTHWEST RESEARCH INSTITUTE
TEST DATE: 07-25-78
TEST NUMBER: 4-4R-4-59
OIL CODE: A (J.D. REF)
DISC CODE: YKXR
PLATE CODE: 004
WEAR
BRONZE: 0.0057
STEEL: 0.0036
MEAN HEAD TEMP, DEG F
320
310
300
290
MEAN INLET OIL TEMP, DEG F
240
230
$\frac{2.25 - 1.80}{1.80} \times 100 = 25.0\%$
STOPPING TIME-SECONDS
2.3
2.2
2.1
2.0
1.9
1.8
0
2
4
6
8
10
12
14
16
CYCLES-THOUSANDS


CATERPILLAR OIL TEST NO. TO-2
LABORATORY: SOUTHWEST RESEARCH INSTITUTE
TEST DATE: 08-10-78
TEST NUMBER: 4-4R-9-64
OIL CODE: D (OEA)
DISC CODE: YKLV
PLATE CODE: 005
WEAR
BRONZE: 0.0028
STEEL: 0.0024
MEAN HEAD TEMP,DEG F
MEAN INLET OIL TEMP,DEG F
STOPPING TIME-SECONDS
CYCLES-THOUSANDS
$\frac{1.875 - 1.750}{1.750} \times 100 = 7.14\%$

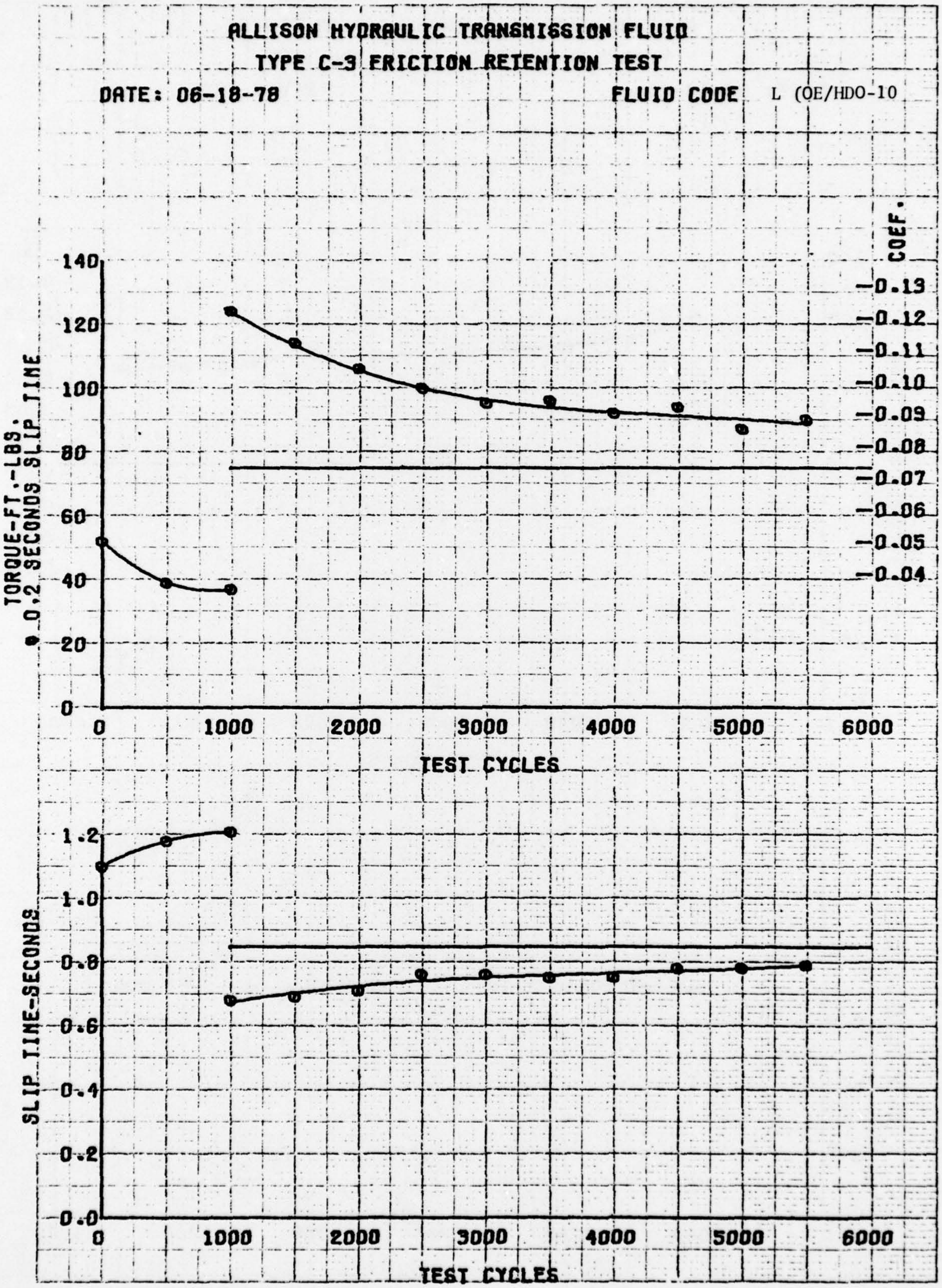

CATERPILLAR OIL TEST NO. TO-2
LABORATORY: SOUTHWEST RESEARCH INSTITUTE
TEST DATE: 07-31-78
TEST NUMBER: 4-4R-6-61
OIL CODE: L (OE/HDO-10)
DISC CODE: YKXR
PLATE CODE: 004
WEAR
BRONZE: 0.0064
STEEL: 0.0034
MEAN HEAD TEMP,DEG F
320
310
300
290
MEAN INLET OIL TEMP,DEG F
240
230
STOPPING TIME-SECONDS
2.1
2.0
1.9
1.8
1.7
1.6
$\frac{1.975 - 1.745}{1.745} \times 100 = 13.2\%$
0
2
4
6
8
10
12
14
16
CYCLES-THOUSANDS



ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-3 FRICTION RETENTION TEST
DATE: 06-20-78
FLUID CODE A(J.D. REF.)
TORQUE-FT.-LBS. @ 0.2 SECONDS SLIP TIME
COEF.
TEST CYCLES
SLIP TIME-SECONDS
TEST CYCLES



ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-3 FRICTION RETENTION TEST
DATE: 06-19-78
FLUID CODE D (OEA)
TORQUE-FT.-LBS. @ 0.2 SECONDS SLIP TIME
COEF.
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
140
120
100
80
60
40
20
0
1000
2000
3000
4000
5000
6000
TEST CYCLES
SLIP TIME-SECONDS
1.2
1.0
0.8
0.6
0.4
0.2
0.0



ALLISON HYDRAULIC TRANSMISSION FLUID
TYPE C-3 FRICTION RETENTION TEST
DATE: 06-18-78
FLUID CODE L (OE/HDO-10
TORQUE-FT.-LBS.
@ 0.2 SECONDS SLIP TIME
COEF.
0
20
40
60
80
100
120
140
0.04
0.05
0.06
0.07
0.08
0.09
0.10
0.11
0.12
0.13
0
1000
2000
3000
4000
5000
6000
TEST CYCLES
SLIP TIME-SECONDS
0.0
0.2
0.4
0.6
0.8
1.0
1.2
0
1000
2000
3000
4000
5000
6000
TEST CYCLES

APPENDIX D
WET-BRAKE CHATTER TESTS ON JOHN DEERE TRACTOR

Test No.	Lub. Code	Variable	Oil Temp, °F(°C) 90(32.2)	120(48.8)	140(60)	160(71.1)	Sum
1&2R	A	Torque*	139	140.5	143	144.5	570
		Chatter*	9.0	5.5	4.0	4.5	23
2	D	Torque	136	152	159	164.5	611.5
		Chatter	27	34	31	26.5	118.5
3R	A	Torque	122	145	158	160	585
		Chatter	13.9	14.0	14.5	9.0	51.4
3	B	Torque	144	152	164	166	626
		Chatter	26.2	28.5	26.3	28.2	109.2
4R	A	Torque	156	165	174	175	670
		Chatter	11.2	6.8	8.6	5.7	32.3
4	E	Torque	164	183	205	200	752
		Chatter	66	55	49	56	226
5R	A	Torque	130	146	153	158	587
		Chatter	5.4	0.6	0.2	0.1	6.3
5	C	Torque	129	148	164	170	611
		Chatter	13.3	3.9	10.7	4.7	32.6
6R	A	Torque	134	145	148	159	586
		Chatter	2.6	2.4	2.0	5.1	12.1
6	F	Torque	---	---	---	---	---
		Chatter	---	---	---	---	Excessive
7R	A	Torque	126	142	156	191	615
		Chatter	8.4	6.9	8.6	8.6	32.5
7	G	Torque	119	125	132	125	501
		Chatter	115	110	113	106	444
8R	A	Torque	165	175	183	187	710
		Chatter	12	12	9	8	41
8	H	Torque	136	154	150	174	614
		Chatter	59	72	65	61	257
9R	A	Torque	132	148	156	164	600
		Chatter	18	14	15	17	64
9	I	Torque	127	166	173	183	649
		Chatter	69	51	64	61	245

*John Deere engineering has commonly rated their fluid as dimensionless Chatter units and torque units
R = Reference Test with JDM-J20A Reference Oil.

APPENDIX D (cont.)

Test No.	Lub. Code	Variable	Oil Temp, °F(°C) 90(32.2)	120(48.8)	140(60)	160(71.1)	Sum
10R	A	Torque	136	154	159	170	619
		Chatter	16.8	13.9	12.6	11.1	54.4
10	J	Torque	143	160	162	170	635
		Chatter	28	22	18.5	19.5	88
11R	A	Torque	180	193	200	208	781
		Chatter	23	18	19	14	74
11	K	Torque	156	206	212	225	799
		Chatter	79	61	64	65	269
12M	**	Torque	155.5	175.5	177	184	692
		Chatter	15.0	13	15	6	49
13R	A	Torque	154	160	171	180	665
		Chatter	15	12	10	8	45
13	L	Torque	161	182	194	191	728
		Chatter	28.5	28.5	25	19.5	101.5
14	A	Torque	160	172	180	192	704
		Chatter	25	13	7	7	52
14	M	Torque	171	186.5	204	206	767.5
		Chatter	47.5	47.5	47.5	46.5	189
3M***	B	Torque	149	171	176	177	673
		Chatter	43	25	17	14	99
5M***	C	Torque	151	176	184	198	709
		Chatter	49	30	26	18	123

** 50/50 blend B & C.

***See AFLRL "Modified" Wet-Brake Test Procedure in Section B of Appendix A.

The torque and chatter values used in this appendix may be converted to lb-in. of torque as follows:

For instance: John Deere Reference Oil

	Sum (Instrument Division)		Calculation Factor		lb-in.
Torque	585	x	9.6×10^3	=	5.6×10^6
Chatter	51	x	9.6×10^3	=	4.9×10^5

This same factor, 9.6×10^3, can be applied to the individual temperature.

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COMMANDER ATTN ATSL-CTD-MS-A US ARMY ORDNANCE CTR AND SCHOOL ABDEEN PVG GD MD 21005	1
COMMANDER ATTN DRCLDC DRCDE DRCMM-SP US ARMY MATERIEL DEVELOPMENT & READINESS COMMAND 5001 EISENHOWER AVENUE ALEXANDRIA VA 22333	 1 1 1
COMMANDER ATTN MR T BAUML ACO DCASMA—SAN ANTONIO 615 E HOUSTON ST BOX 1040 SAN ANTONIO TX 78294	2
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